Large-Scale Structure in the ROSAT North Ecliptic Pole Survey

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Abstract. We have used the ROSAT All-Sky Survey around the North Ecliptic Pole to construct a complete sample of galaxy clusters. The deep and contiguous nature of the survey affords us the opportunity to examine large-scale structure in the Universe on scales of hundreds of megaparsecs. We have identified over 99% of the 446 X-ray sources in the survey area. The cluster sample consists of 65 objects with redshifts approaching unity. Surprisingly, some 20% of the clusters exists in a wall-like structure at z=0.088 spanning the entire $9^\circ \times 9^\circ$ survey region. This is a very significant extension of both the membership and the spatial extent to a known supercluster in this location.

1 Introduction

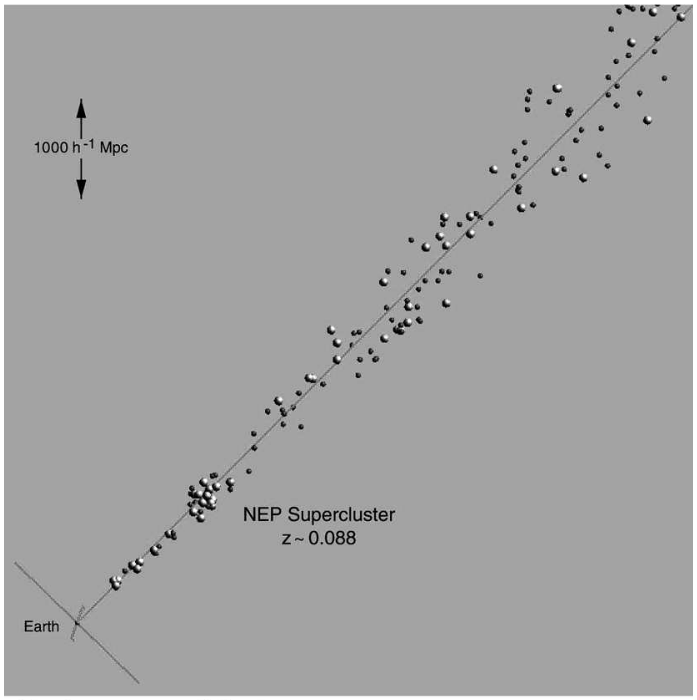
Within the ROSAT All-Sky Survey (RASS) [7], the region around the North Ecliptic Pole (NEP) is special because the exposure here is deepest where the great circle scans overlap. Furthermore, galactic obscuration is not severe here at a galactic latitude of $+30^\circ$. Note the South Ecliptic Pole exposure depth is degraded by the South Atlantic Anomaly and the extragalactic sky in this direction is partially obscured by the Magellanic Clouds.

Over the last nine years we have executed a systematic optical/NIR followup program of imaging and spectroscopy primarily at the Mauna Kea observatories. We have identified the physical nature of 99.3% of the 446 X-ray sources detected at greater than 4 sigma in the $9^\circ \times 9^\circ$ survey region. The initial observing phase of this project is now complete, and our emphasis is shifting to analyzing the statistically complete, X-ray selected samples.

2 The Cluster Sample

We have constructed the NEP cluster sample to examine X-ray cluster luminosity evolution and to characterize large-scale structure (LSS). The initial evolution results are presented by I. M. Gioia in these proceedings. Here we present the preliminary findings on LSS.

We emphasize the cluster sample is unique in that it is both deep and contiguous. The sample consists of 65 objects discovered in a 81 square-degree region with a median sensitivity reaching 8×10^{-14} erg s^{-1} cm^{-2}.



Animation sequences available at http://www.ifa.hawaii.edu/~mullis/nep.html

Figure 1: 3D view of the near section of the conical NEP survey volume. The Earth is at the origin with the long, redshift axis through the NEP. Bright, large spheres are clusters and groups of galaxies. Small, dark spheres are AGN.

The observed NEP cluster redshift distribution shows a striking feature at z=0.088. Fifteen clusters lie in the redshift interval 0.07 to 0.10, an impressive 23% of the entire sample. This interval is 4 to 5 times more populated than expected which is significant at the 4 sigma level. The complex spans the entire survey area.

3 The NEP Supercluster

LSS has been previously seen in the direction of the NEP. Fourteen years ago Batuski & Burns [2] produced a finding list of candidate superclusters based on a percolation analysis of Abell clusters. They found an association of 6 Abell

clusters approximately 5° from the NEP. Subsequently Burg et al. [3] reported 5 X-ray cluster candidates detected in an early ROSAT pointed observation possibly related to this supercluster.

IRAS mapped the sky in a fashion similar to ROSAT and hence has the same super-sensitivy at the NEP. Ashby et al. [1] endevoured to test starburst galaxy evolution with a sample of IRAS NEP galaxies but instead were overwhelmed by LSS. Fifteen galaxies, 20% of their IR selected sample, turned up at z=0.088. Rinehart et al. [5] have expanded the IRAS survey to the same area on the sky as our survey, and they continue to see a "massive" sheet of galaxies, estimated to be 3 times as dense as the Great Wall. A final signature of structure in the NEP region is a low-z Lya absorber detected at z=0.089 in the direction of a well-known QSO H1821+643 from Tripp et al. [6].

We have prepared an animated, three-dimensional "fly-through" of the NEP survey volume which is available over the web at *http://www.ifa.hawaii.edu/∼mullis/nep.html*. Fig. 1 presents a demonstrative frame from the animation. Thanks to the ROSAT NEP Survey we have a much improved understanding of the NEP supercluster. We have more than doubled the physical size of the original Batuski & Burns supercluster and tripled the cluster content. We now know it to consist of at least 20 clusters and groups and 12 NEP-detected AGN. It has a planar distribution of $70 \times 70 \times 25\ h^{-1}$ Mpc with a 12° extent on the sky.

The NEP structure compares favorably in size and content relative to well-known objects such as the Great Wall and the Shapley Supercluster. It is not the largest nor the most dense but one of the most robustly sampled. Twenty X-ray emitting clusters of galaxies demark the highest density regions while the over sixty IRAS galaxies and AGN trace out the lower density domains. Furthermore, the door is open for the supercluster to be even larger; its depth and thickness are well-constrained but its breadth is currently not bound. We have only examined one side of the original NEP supercluster.

4 LSS at the NEP - Work in Progress

We are currently working to chart the true extent of the NEP supercluster by discovering additional galaxy clusters beyond the original NEP survey region. Optical and X-ray followup observations will be used to examine the dynamical state of the structure. Is it, or any portion of it, gravitationally bound? Are alignments between clusters detectable in their X-ray contours? The supercluster's edge-on aspect makes it an attractive candidate in which to search for X-ray filaments.

Here we have largely concentrated on the NEP supercluster. But the rest of the cluster sample should not go unscrutinized. Lesser examples of clusters of clusters, potential superclusters, are visible in three-dimensional examinations. A correlation function analysis will quantify the degree of clustering present.

The NEP AGN sample of 211 objects is another means for examining LSS. Though they are more sporadic markers compared to clusters, they reach to greater depths (z_{max} ∼4). Our sizable collection is free of the serious selection effects that plague non-X-ray selected samples. There are several instances of clusters of AGN visible in three-dimensions. The global clustering characteristic of the AGN will be determined via a correlation analysis.

5 Summary

Experimental design and serendipity have converged at the NEP to reveal a remarkable element of LSS in the X-ray Universe. The NEP supercluster is very large and likely even larger. A better reckoning of its girth and content have been revealed by X-rays. There are more LSS results to come from the NEP cluster and AGN samples. Finally and perhaps most importantly, the ROSAT NEP survey demonstrates the effectiveness of X-rays for studying LSS and opens the door for future X-ray survey missions to pursue the subject further.

Details of the NEP supercluster discovery in the ROSAT NEP survey will be presented in a forthcoming paper by Mullis et al. [4].

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